

HIGH REPETITION RATE SEALED CO<sub>2</sub> TEA LASERS

## USING HETEROGENEOUS CATALYSTS\*

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## INTRODUCTION

The significant operational advantages offered by CO<sub>2</sub> lasers, operating in the 10.6 micron region of the spectrum, over current solid state lasers, emitting in the near I.R. region of the spectrum, have prompted increased interest in the development of compact, reliable, rugged CO<sub>2</sub> laser sources. Perhaps the most critical aspect associated with achieving a laser compatible with military use is the development of lasers which require no gas replenishment.

Sealed, single shot, CO<sub>2</sub> TEA lasers have been available for a number of years. Stark et al were first to demonstrate reliable sealed operation in single shot CO<sub>2</sub> TEA lasers in 1975 (reference 1) using gas catalysis. GEC Avionics reported the compact, environmentally qualified, MKIII CO<sub>2</sub> TEA laser with a pulse life of greater than 10<sup>6</sup> pulses in 1980 (reference 2).

A sealed laser lifetime of greater than 10<sup>6</sup> pulses is acceptable for single shot cases, such as direct detection rangefinders for tank laser sights. However, in many other applications, such as tracking of fast moving targets, it is essential that a repetition rate of typically 30Hz to 100Hz is employed. In such cases, a pulse lifetime of 10<sup>6</sup> pulses is no longer sufficient and a minimum pulse lifetime of 10<sup>7</sup> pulses is essential to ensure a useful service life. In 1983 Stark et al (reference 3) described a sealed, 100Hz CO<sub>2</sub> TEA laser, with a life of  $>2.6 \times 10^6$ , which employed heterogeneous catalysis. Following this pioneering work, GEC Avionics has been engaged in the development of a sealed high repetition rate lasers and in the following a pulse lifetime of 20 million pulses is demonstrated.

## FACTORS INFLUENCING LIFETIME

The single most critical factor dictating the attainment of a sealed lifetime is the chemical reactions which occur in the discharge of the pulsed CO<sub>2</sub> TEA laser. The electrical discharge dissociates CO<sub>2</sub> forming CO and oxygen, primarily as a result of direct electron impact (2 body attachment). A typical three gas mixture, tends to dissociate linearly with the number of pulses and a glow to arc transition is obtained whenever the negative ion concentration becomes comparable with the electron concentration. Thus, to control arcing in these lasers, steps must be taken to control the negative ion concentration, which in turn means the O<sub>2</sub> concentration must be controlled. Typically the oxygen concentration must be limited to <1% in order to guarantee prevention of arcing (though the actual oxygen tolerance of a particular system is a strong function of the laser design).

In lasers employing low concentrations of CO<sub>2</sub> (i.e. <15%) gas additives are a particularly successful technique to control the oxygen buildup. For high CO<sub>2</sub> concentrations, more effective forms of catalysis can be employed. In this case the

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catalytic recombination rate must be matched with the dissociation rate, dictated by the  $\text{CO}_2$  concentration and the repetition rate. However, it would be incorrect to imply that the gas chemistry effects outlined above are the sole factor influencing laser lifetime. Many additional factors are important including:

- a) Gas contamination
- b) Excess or slow electrical excitation
- c) Electrode assembly and condition
- d) Inadequate or limited preionization
- e) Optical deterioration

where items b) to d) tend to enhance the criticality of controlling the gas chemistry. Also important are aspects of the laser construction including materials employed, mechanical sealing techniques used, and cleaning and processing schedules. Thus successful sealed laser performance is related to the optical, mechanical and electrical design of the laser, the design of the external drive circuit, and the control of the gas chemistry.

#### LIFETEST LASER DESIGN

The basic design of the test-bed laser constructed for sealed lifetime studies is indicated in Figure 1. This shows a schematic cross section of the laser normal to the optic axis. The electrode structure consists of a pair of solid metal electrodes preionized by either sliding arc arrays or semiconductor plates. The electrodes are profiled so that the field decreases uniformly in all directions away from the uniform field region between the electrodes. The arc array preionizer geometry is similar to that described previously (reference 1) while the semiconductor preionizers consist of slabs of low resistivity silicon mounted close to the high voltage electrodes. The total discharge volume is  $11\text{cm}^3$ .

A tangential fan is used to provide the closed cycle gas circulation necessary for operation at high repetition rates. A gas flow velocity of typically  $2\text{ms}^{-1}$  is used to provide a clearing ratio of greater than 2. The fan is driven from an external motor via a magnetic fluid leadthrough. Since the laser operates continuously, fluid cooling of the laser is provided to remove the heat dissipated by the discharge.

A room temperature, tin-oxide/precious metal CO oxidation catalyst is placed in the gas flow. Two forms of catalyst have been tested. The first is supplied by UOP Limited (UK) and is in pellet form. The pellets are supported on a suitable substrate and the mass of catalyst pellets is selected to provide sufficient recombination for the conditions under which the laser will be operated. The second form of catalyst is supplied by AERE (Harwell) and in this case the catalyst is supported on a ceramic monolith. Both forms of catalyst are mechanically strong and are resistant to powdering.

The cavity reflectors consist of a plane, 100% gold on copper mirror and a plane, zinc selenide, partial reflector, both of which are mounted on an internal optical frame. The intracavity aperture constrains the laser to the fundamental mode. The cavity reflectors for the test-bed lasers are easily removed to facilitate inspection and can be aligned during the lifetests without opening the laser. The cavity is designed such that the internal power density is limited to a value significantly lower than the measured laser damage threshold of the optics.

The gas envelope of the laser head is a welded stainless steel structure, which has been designed to give maximum experimental flexibility during the ongoing experimental program. As a consequence the physical size of the laser at 2.4 liters is significantly larger than is required for the nominal design performance of a 1MW peak power, 100mJ pulse energy.

The lifetests were conducted with the laser operated in the test set-up illustrated in figure (2). The laser is driven from a standard, spark gap switched, single energy storage capacitor, pulse forming network, charged to typically 30kV. The laser is connected to an IR CO analyser and a paramagnetic O<sub>2</sub> analyzer. This permits the gas composition in the laser to be monitored in situ during the lifetest, thus avoiding interference with the experiment. Measurement of the pumping speed of the catalyst can also be made.

The pumping speed is determined periodically during a lifetest by switching the laser off and measuring the change in O<sub>2</sub> partial pressure with time. The partial pressure, P at time, t, is give by

$$P = P_0 - \frac{mA}{V}t$$

Where P<sub>0</sub> is the partial pressure at t<sub>0</sub>  
 V is the volume of the laser  
 A is the specific volumetric pumping speed  
 m is the mass of catalyst.

The oxygen volumetric pumping speed is thus the rate of removal of oxygen per gram of catalyst and is a useful measure of the activity of the catalyst in relation to oxygen recombination. From a semi-logarithmic plot of oxygen partial pressure and time, 'A' may be readily determined from the slope.

In addition to gas compositions and catalyst activity, the laser output power, energy, divergence and discharge characteristics are monitored throughout the lifetests.

The system described has been used to conduct a series of sealed lifetests and the results obtained are indicated below. In all the tests discussed the gas mixture employed was a 1:1:1 mixture of CO<sub>2</sub>, N<sub>2</sub> and He, and the repetition rate was 30Hz to 50Hz.

## RESULTS

Figure (3) shows the variation in output energy of the laser as a function of the number of pulses. In this test the laser was preionized by a pair of sliding arc-arrays, and a UOP catalyst was employed. Over the 10<sup>7</sup> pulses of the test the output remained essentially constant, and at the termination of the experiment the laser was completely stable.

Similarly, figures (4), (5) and (6) show the performance of the laser over a 10<sup>7</sup> lifetest using a Harwell catalyst and arc-array preionization. The peak power and pulse energy exhibit little degradation over the duration of the test, while, the pumping speed of the catalyst is unchanged at the end of the test, though there is an increase observed during the first 2.0 x 10<sup>6</sup> pulses. Thus the initial pumping speed of 32 cc/s/g is maintained over the 10<sup>7</sup> pulses, indicating the

catalytic activity is not degraded. Figures (7) and (8) show the behavior with the UOP catalyst and arc array preionization over a 20 million pulse lifetest. The critical laser parameters are only reduced by typically 10%. The same performance is also obtained in the complementary tests using the Harwell catalyst.

The above tests all employed arc-array preionization. Results obtained using semiconductor preionization have been equally successful.

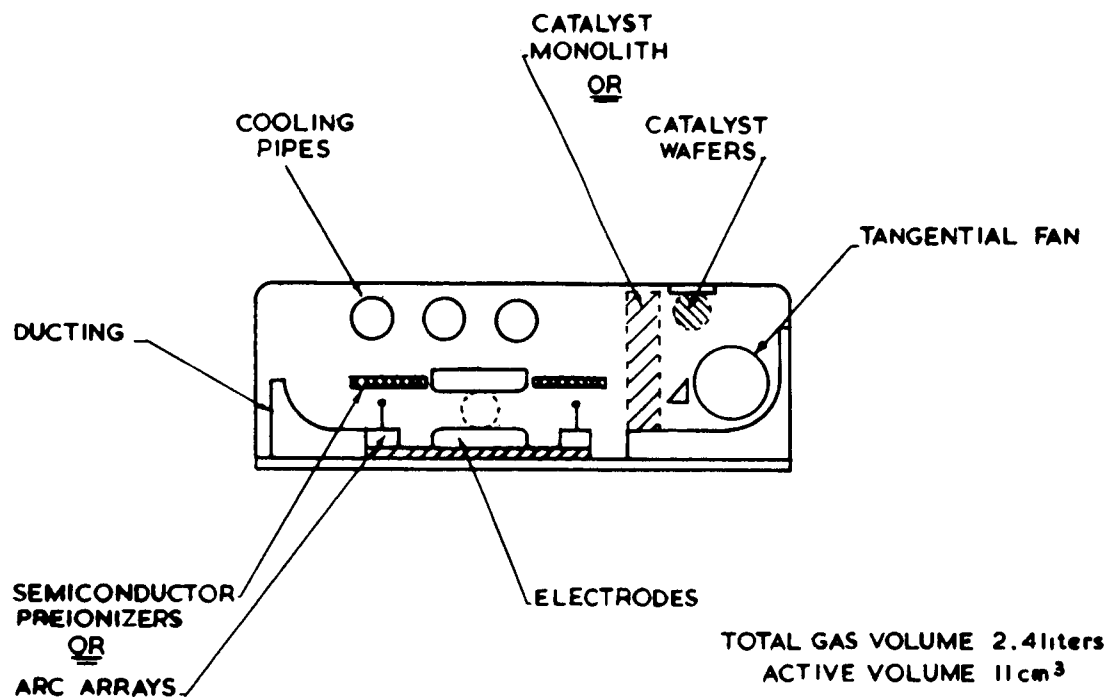
During the lifetest program we have also demonstrated a cumulative life of  $10^8$  pulses for some of the major components of the laser. This includes laser resonator optics and arc array preionizers. In the latter case, arc array erosion over the  $10^8$  pulses resulted in an increase in arc gap and a consequent increase in the delay of the arc array preionizing discharge. This latter effect would not present a difficulty where the arc arrays and main discharge arc fired independently. However the accumulation of eroded material within the laser could result in deleterious effects if remedial action is not taken.

#### CONCLUSIONS

In the course of the lifetest program described it has clearly been demonstrated that our essential lifetime requirement of  $10^7$  pulses has been achieved and that the desirable lifetime of  $10^8$  pulses appears feasible. To obtain such a lifetime reliability, or even extended it further, additional work is required to investigate, for example, the long term stability of the catalyst and identify any catalyst effects which have not yet become to manifest, to study accumulated optical effects to resonator reflectors, and to address engineering factors such as erosion products of active elements in the laser.

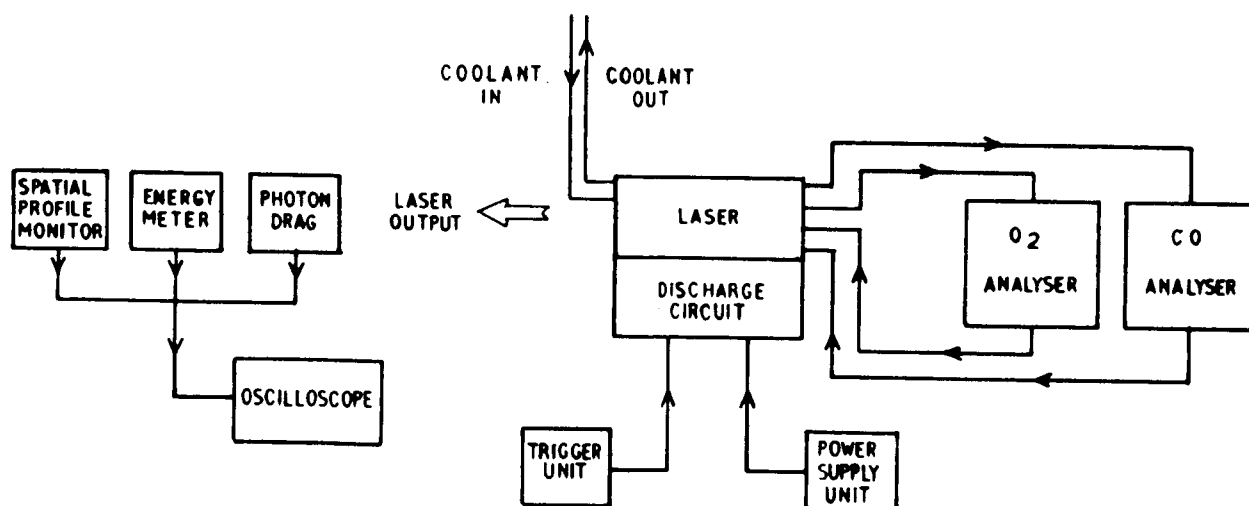
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2. H. T. W. Price SPIE Vol 227 CO<sub>2</sub> Laser Devices and Applications, 48, (1980).
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SCHEMATIC OF LIFETEST LASER

Figure 1



LIFETEST LASER TEST SET-UP

Figure 2

SEALED LIFETEST WITH C358 CATALYST WAFERS  
OUTPUT ENERGY Vs NUMBER OF PULSES

LASER GAS MIX 1CO<sub>2</sub>:1N<sub>2</sub>:1He

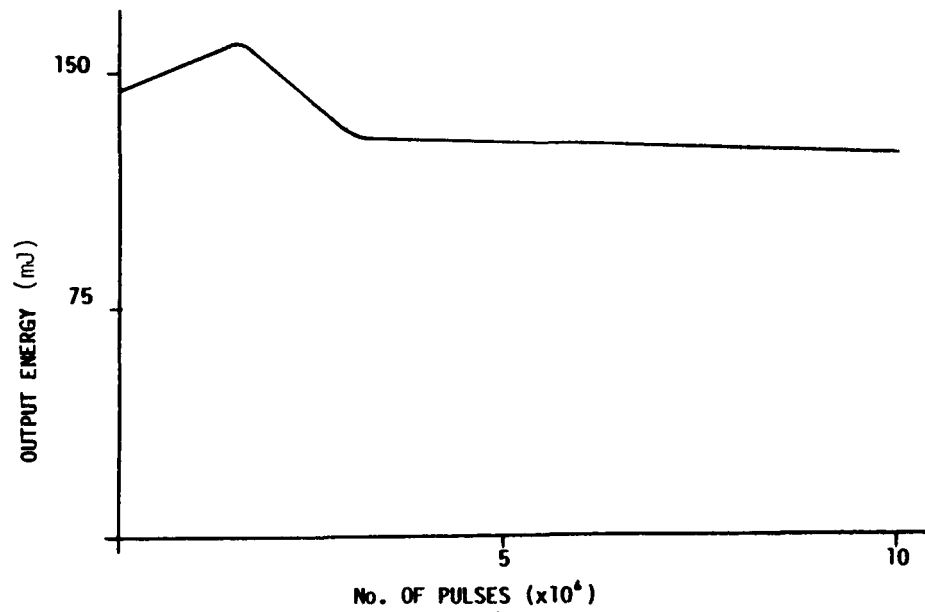


Figure 3

SEALED LIFETEST WITH CATALYST MONOLITH #2  
OUTPUT ENERGY Vs NUMBER OF PULSES

LASER GAS MIX 1CO<sub>2</sub>:1N<sub>2</sub>:1He

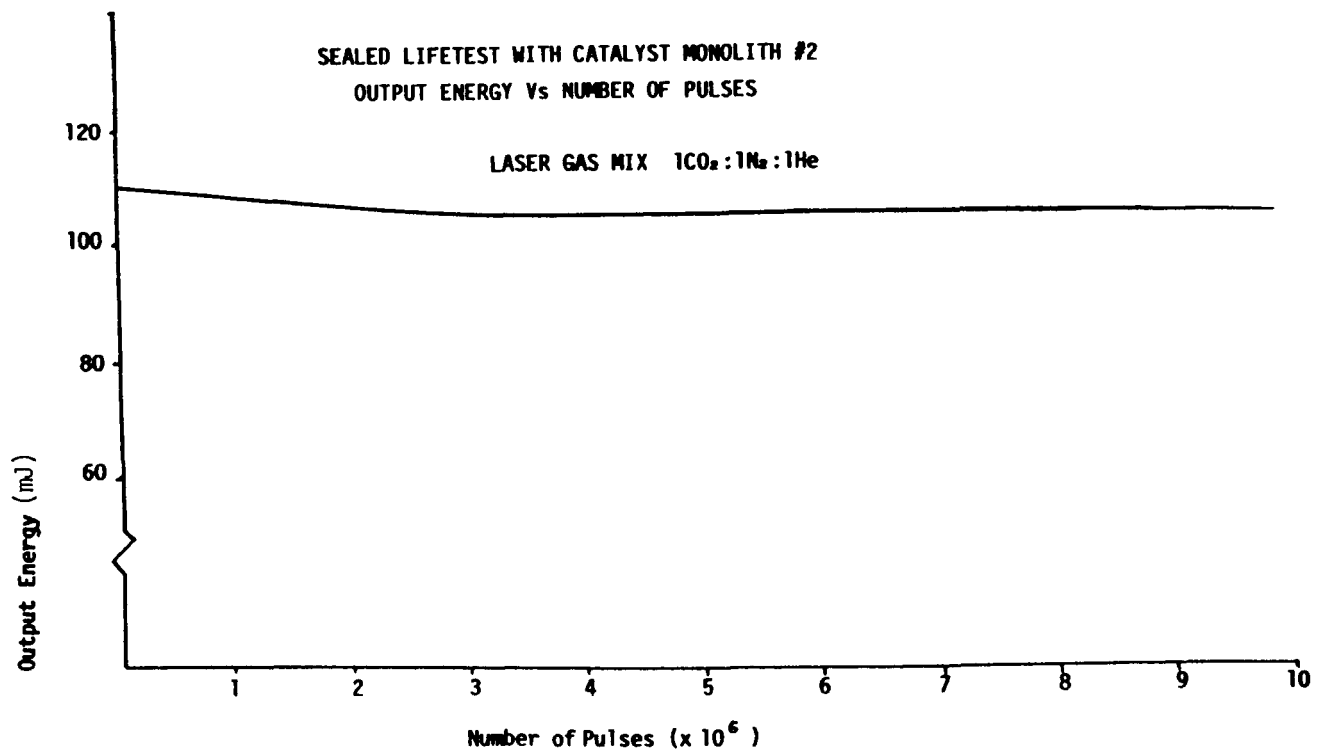


Figure 4

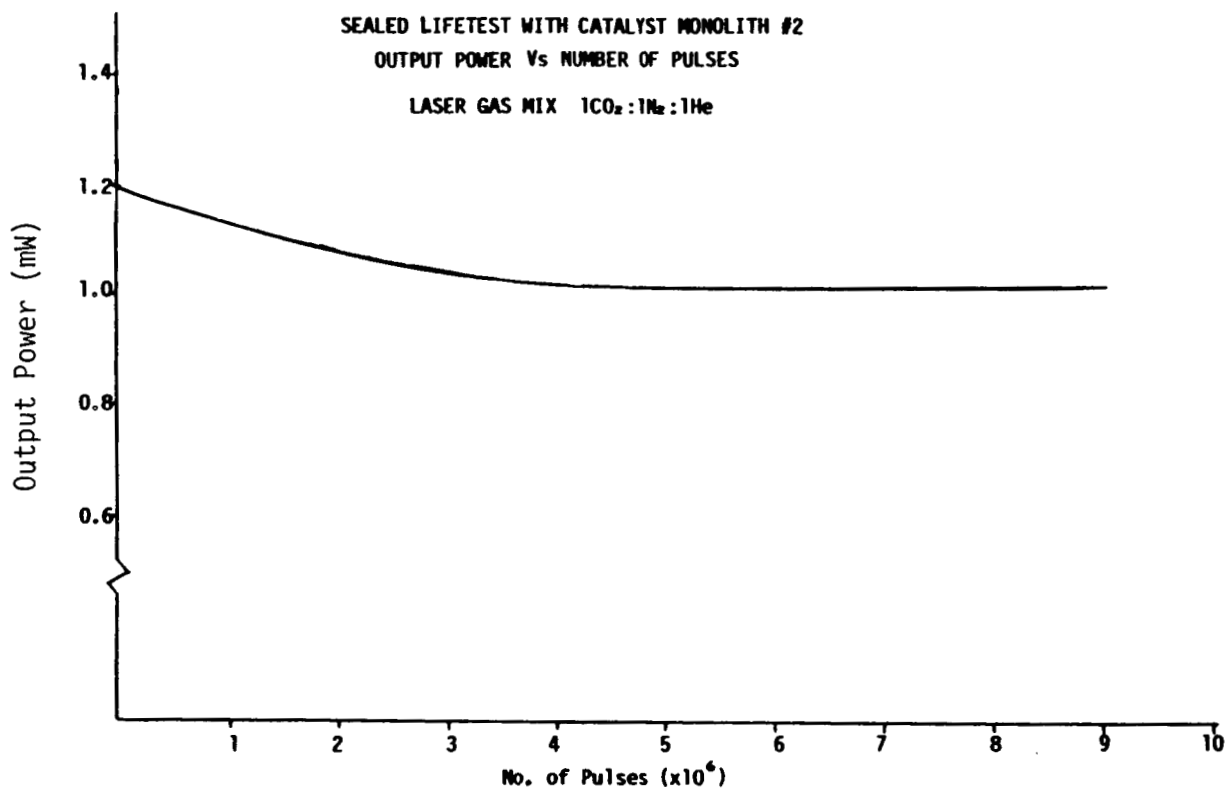


Figure 5

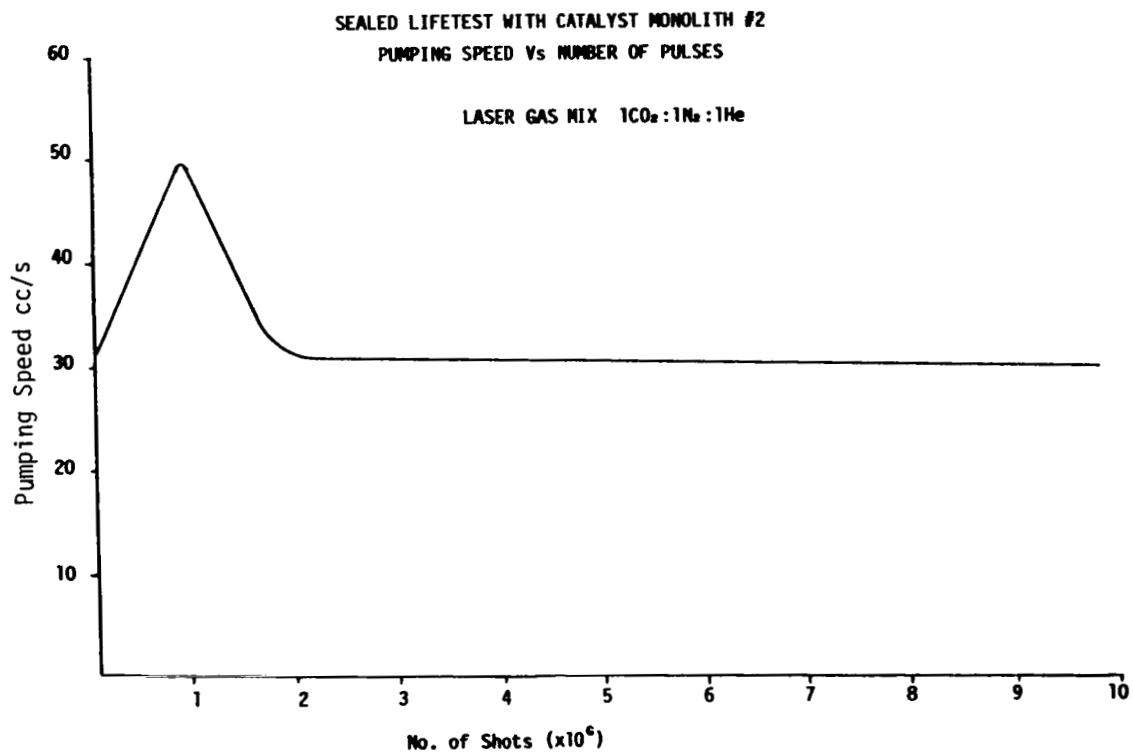


Figure 6

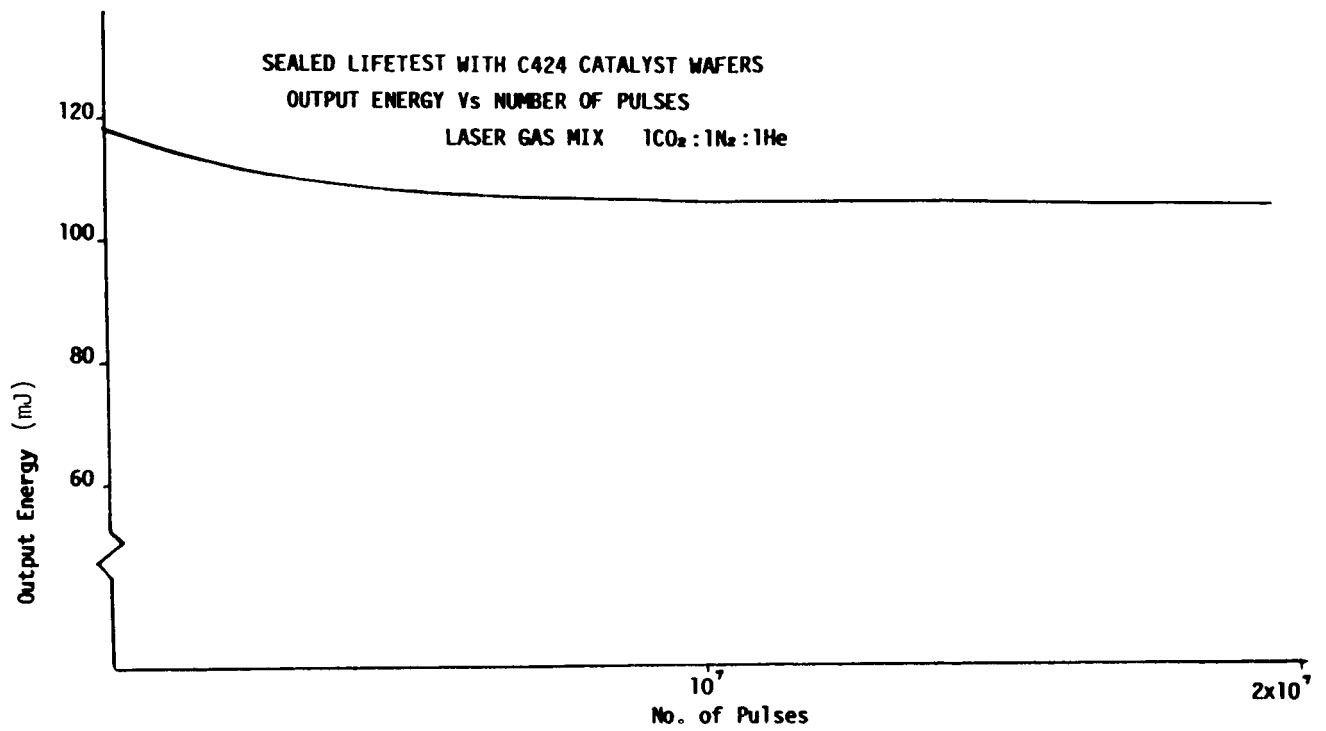


Figure 7

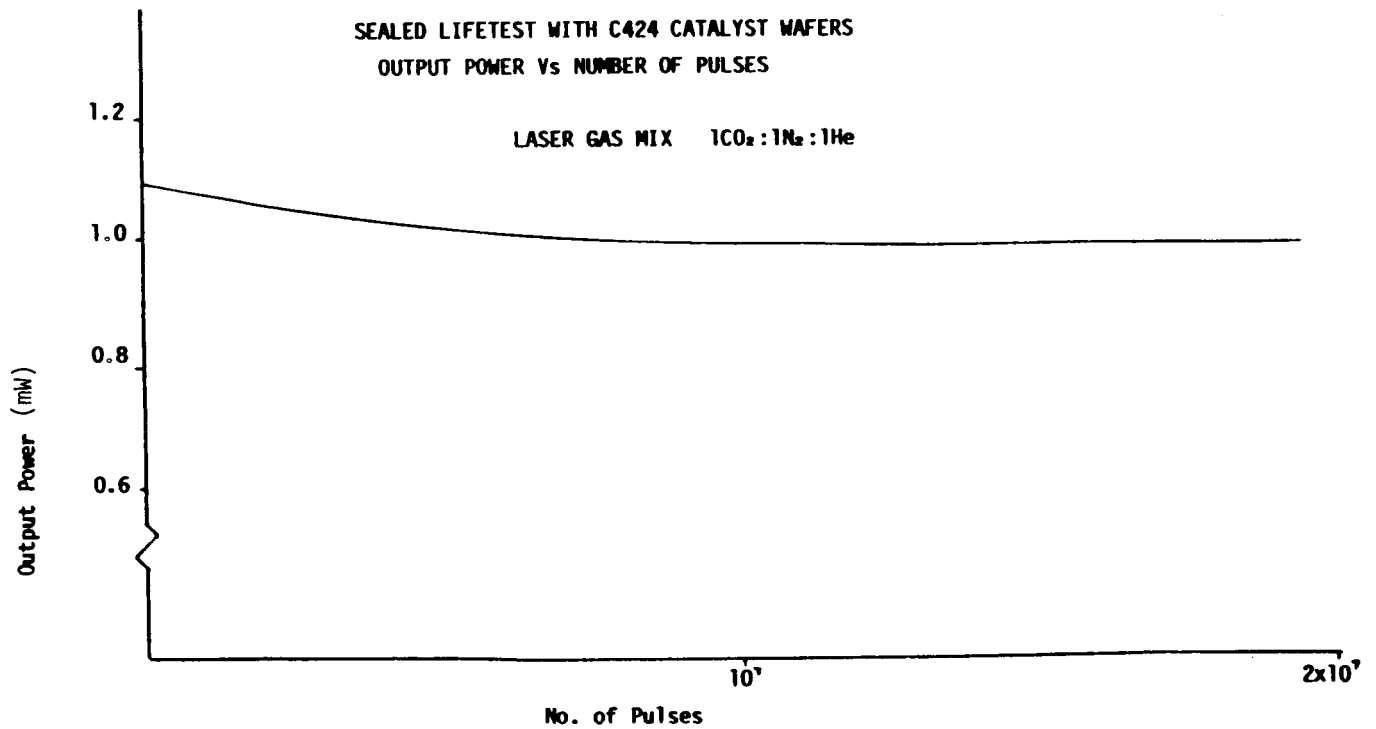


Figure 8